

Effects of tree-length timber skidding on soil compaction in the skid trail in Hyrcanian forests

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Abstract

Aim of study: The study was conducted to examine impact of skidding traffic, trail slope, traffic frequency, and soil depth on the soil bulk density.

Area of study: This study was carried out in the Kheyroud Forest in Hyrcanian forest, Iran.

Material and methods: The level of soil compaction at eight levels of traffic (1, 4, 8, 10, 15, 20, 25, and 30 passes), four levels of skid trail slopes (0, 10, -10, and -20%) and three soil depth (5, 15, 25 cm) were applied in three replicates consequently. Bulk densities were measured on the undisturbed surface (control) and within the tracks. Timbers were extracted in the tree-length logging method using rubber-tired skidder (Timberjack 450 C).

Main results: About 5.2% of total area of harvesting unit were disturbed and compacted. Uphill skidding increases compaction more than downhill skidding. In the four different slopes, the highest increasing of the bulk density was occurred during the first few passes of skidder, although the bulk density continued to increase in amount and depth with the number of passes. The increases in bulk density were still important at the maximum sampling depth of 20-30 cm.

Research highlights: The results indicated that slope steepness had a strong effect on the soil physical properties and soil disturbance. Designated skid trails should be used to minimize the influence on the forest soil.

Key words: soil compaction; tree-length logging method; rubber-tired skidder; Hyrcanian forest.

Introduction

Highly mechanized systems, such as harvesters, forwarders and feller-bunchers, are not used because, most of the forests are located on mountainous sites with steep slopes and the stands are dominated by mature hardwood trees. The use of wheeled and tracked skidders is a widely seen and well accepted practice in Hyrcanian forests. It is also the one that tends to cause the greatest environmental problems. In this forest, the degree and extent in mechanization of skidding operations has greatly intensified over the last decade, and general public and forest managers are currently expressing concern about the compaction and degradation of forest soils and its consequences such as surface run-off, soil erosion, and flood flow risk. Forest soils, in general, are susceptible to compaction as they are loose with high organic-matter, are generally low in bulk density, high in porosity, and low in strength

(Froehlich *et al.*, 1985; Kolkaa and Smidt, 2004; Horn *et al.*, 2004). The impact of skidding operations on forest soils can be divided into three major categories: soil profile disturbance, soil compaction and soil puddling and rutting (Cullen, 1991; Rab, 1996).

During timber harvesting the degree of soil compaction depends on various factors including: site and soil characteristics (Ampoorter *et al.*, 2007) such as soil texture (Rohand *et al.*, 2004), Soil moisture (Greacen and Sands, 1980), the number of machine passes (Wang *et al.*, 2007), harvesting system (Froehlich *et al.*, 1985), type of machine (Susnjar *et al.*, 2006), and its characteristics includes: mass of vehicles and loads (Krag *et al.*, 1986, Nugent *et al.*, 2003), type, number of wheel and the inflation pressure of the tire (Eliasson, 2005), amount of logging slash (Eliasson and Wasterlund, 2007), organic matter (Rohand *et al.*, 2004). The most of the soil compaction occurs during the first ten passes of a vehicle with the most occurring

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Received: 18-11-12. Accepted: 09-01-14.

This work has four Supplementary Figures that do not appear in the printed article but that accompany the paper online.

in the first three trips (Froehlich *et al.*, 1985). Subsequent passes generally have little additional effect (Ampoorter *et al.*, 2007; Bolding *et al.*, 2009), but bulk density also increased significantly after more than 3 passes (Gayoso and Iroume, 1991). Picchio *et al.* (2012) studied the machinery-induced soil compaction in thinning two pine stands in central Italy and indicated that the penetration resistance of soil increased by about 50% and shear resistance by almost 40%.

In Hyrcanian forest, a few studies have been carried out about the effects of timber extraction on soil compaction and bulk density. Jamshidi *et al.* (2008) measured the changes in bulk density in the top 10 cm of soil following machine and animal skidding in Hyrcanian forest. They found that average soil bulk density in the tracks of machine skid trails was significantly greater than the soil density outside the tracks. The specific objectives were to: quantify the extent of trail area and winching line (disturbance area) throughout the harvest unit, to characterize and establish the threshold levels for the machine traffic with respect to bulk density and slope gradient or direction of skidding for three different soil depths due to tree-length timber transportation in skid trails.

Material and methods

Study area

The research was carried out in Compartment No. 209 of Namkhaneh district, in Kheyroud Research Forest Station in the Hyrcanian forest region in the north of Iran. The compartment has an altitude range of 850–1,010 m asl, and the forest lies on an eastern aspect. Average rainfall range from 1420 to 1530 mm/year, is heaviest in summer and autumn and mean annual temperature is 8.5°C. The forest stand was uneven aged with average growing stock of 422 m³ ha⁻¹. This area is dominated by natural forests containing native mixed deciduous tree species including *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Acer velutinum* Boiss and *Alnus subcordata* C.A.Mey. The silvicultural regime is selection based, with harvesting as a combination of group selection and single tree selection. Field data were collected during August and September of 2010. The soil of study site is classified as a brown forest soil (*Alfisols*) and well-drained. The texture of the soil is ranging from silt loam to loamy.

Selected trees for harvesting are felled by chain-saws, limbed and topped at the stump. Felled trees are bucked with chainsaws into saw logs and pulp logs. Logs with a 12 to 15 meter length are extracted by wheeled skidders with winch to roadside landings and the fuel woods are extracted by mules. The skid trail slope ranges from –20 to 35%. Table 1S summarized some characteristic of study site (Suppl. Table S1).

Experimental design and data analyses

A rubber-tired skidder (Timberjack 450C) was used to extract felled timber. The Timberjack 450C is normally an articulated, four-wheel-drive vehicle weighing 10.3 ton with engine power of 177 hp (132 kW). It is equipped with a blade for light pushing of obstacles and stacking of logs. The skidder was fitted with size 24.5–32 tires inflated to 220 kPa on both front and rear axles, and it had a ground clearance approximately 0.6 m with overall width of 3.1 m. The average logged volumes in each pass were 6.5 cubic meters and total load were 200 m³. The average skidding and winching distances to the landing area near forest roadside were 480 m and 42 m, respectively.

Twelve sampling transect were selected at different slope gradients along the designated skid trail for bulk density measurements (Fig. 1). Before skidding operation, four slope gradients in the skid trail with 3 replications were established in areas at 0–10 cm soil profile depth, and the different levels of compaction were applied by varying the levels of machine traffic: 0 (control), 1, 4, 8, 10, 15, 20, 25, and 30 machine passes. A pass implies a drive back and forth the selected trail. Four slope gradients of skid trail were 0 (flat trail), 10%, –10% and –20%. Also, prior to any skidding operations and after 20 skidder pass, bulk density was

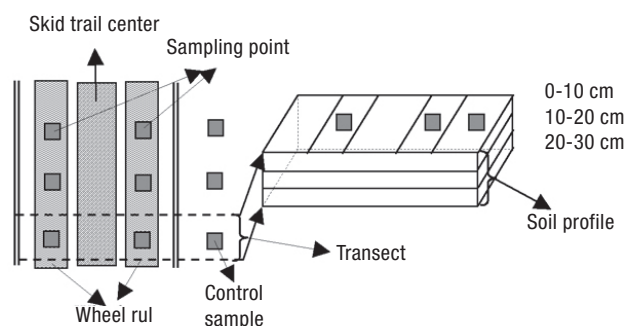


Figure 1. Experimental design of the field trail for the bulk density sampling.

measured at this four slope gradient of trail (flat trail, 10%, -10%, and -20%) at the 5 cm, 15 cm, and 25 cm soil profile depths in wheel rut and control sample point adjacent skid trail. The soil sample cores were obtained from the layers of the mineral soil using a thin walled steel cylinder, 40 mm long and 56 mm in diameter, driven into the soil by a hammer-driven device. After extracting the steel cylinder from the soil with minimal disturbance to the contents, the soil cores were trimmed flush with the cylinder end and extruded into a plastic bag for transporting to the laboratory. Total 189 and 27 samples were measured for assessing different level of soil compaction and bulk density change with soil depth. Samples were weighed on the day they were collected and again after oven drying at 105°C for 24 h to determine water content and bulk density.

The experimental design was a factorial arrangement of treatments conducted in a completely randomized design. We also applied general linear modeling (GLM) to relate bulk density to machine passes, slope gradient, and depth in relation to the skid trails. Post-hoc comparison of means was performed using Duncan's multiple designs to mean-based grouping with a 95% confidence level. Analysis of variance of the data was conducted in SPSS (release 15.0) to identify differences between bulk density values of four slope gradients in skid trails. Treatment effects were considered significant if $p < 0.05$. Soil bulk density before and after skidder operations was compared using independent samples t-test.

Results

A detailed survey of the harvested unit following extraction with a cable skidder indicated that 3.9% of the total area (19 hectare) was covered with skid trails and an additional 0.7% of the unit was occupied by the landing. In this study, winching of timber on the ground from felling site to the skidder had substantial effect on soil displacement that occupied 0.6% of the total area. Finally, in this study 5.2% of total area of harvesting unit were disturbed and compacted.

Table 1 shows the analysis of the soil bulk density data as influenced by machine passes and slope gradient for the cable skidder. Results showed that machine passes and slope gradient, and the interaction effects of machine passes \times slope gradient were all significant variables ($p < 0.05$).

Table 1. Analysis of variance (ANOVA) for the effect of number of machine passes (NP) and slope gradient (SG) on bulk density in 0-10 cm soil depth

Source	SS	df	MS	F	P
NP	1.576	8	0.197	556.9	0.00
SG	0.156	3	0.052	147.44	0.00
NP \times SG	0.058	24	0.002	6.85	0.00

The independent samples t-test indicated that skidding had a statistically significant effect on the bulk density of machine trails before and after machine passes (Fig. 2). Result shows that bulk density significantly increased as number of machine pass increased (Suppl. Fig. S1), regardless of slope gradient, the degree and level of compaction differed among trail slope using Duncan's multiple range test (Suppl. Fig. S2). In the other hand, generally, trails with four slopes show a similar trend of increasing soil bulk density with increasing amounts of machine passes. In flat trail, the bulk density in the 0-10 cm of soil (1.08 g cm^{-3}) increased by 10% after 1 pass, 20% after 4 passes, 25% after 8 passes, 31% after 15 machine passes. In trail with a 10% slope or uphill skidding, the soil bulk density (1.06 g cm^{-3}) increased by 27% after 1 pass, 42% after 4 passes. Subsequent increase of number pass to 30 turns did not increased bulk density significantly.

High level of increase in bulk density was occurred after 4 machine passes and additional increase of machine pass did not increase bulk density significantly. In area with -10%, bulk density (1.05 g cm^{-3}) increased by 21% after 1 pass, 31% after 4 passes, 39% after 8 turns and in trail with -20% slope, by 16% after 1 pass, 25% after 4 passes, 35% after 8 turns and 40%

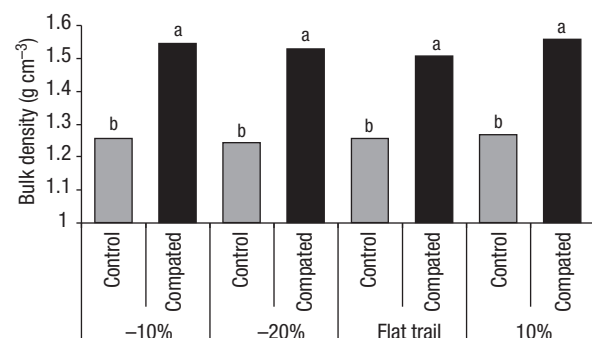


Figure 2. Average of the bulk density in g cm^{-3} and its relative changes before and after skidding in each of the slope gradient of trail and by independent samples t-test. Values are mean. Different letters within each slope treatments shows significant differences ($p < 0.05$).

after 10 passes. In flat trail, the highest rate of compaction, as bulk density increased, took place during the 15 first passes by 1.39 g cm^{-3} . In trail with 10% slope gradient, in contrast, high increase in bulk density was observed to 1.48 g cm^{-3} which occurred after 4 machine passes. Also, in downhill skidding with -10% and -20% , bulk densities were increased significantly after 8 and 10 machine passes, respectively. Then, soil bulk density for -10% and -20% at these levels were 1.44 and 1.42 g cm^{-3} , respectively. Bulk density in the 10% trail showed the highest value in comparison with other slope gradient of trail. Skidding operations along flat trail show the lowest compaction by Duncan's test.

Table 2 shows the analyses of the soil bulk density data as influenced by position (compacted and control samples), slope gradient and depth after 20 machine passes. Results showed that position, depth, slope gradient, and the interaction effects of position \times slope gradient and position \times depth were all significant variables ($p < 0.05$). The general linear model revealed that the significant interactions were position \times slope gradient ($p < 0.01$) and position \times depth ($p < 0.01$). It can be noticed that bulk density values of control sample (no pass) in four slope gradient are clearly higher than compacted values. The interaction between position and depth was also significant.

After 20 machine passes, bulk density increased in depth under the skid trails in all slope gradient of trails, but the major increases occurred in the top of the soil profile at 0–10 cm. In trails with a 10% slope, the increase in bulk density for all depths was significantly higher as compared with those observed in trails with a -10% , -20% slope, and flat trail. The independent samples t-test indicated that skidding had a statistically significant effect on the bulk density of machine trails before and after machine passes in soil depth (Suppl. Fig. S3). Deeper in the soil profile, differen-

ces between control and the treatments in four slope gradient became smaller (Suppl. Fig. S4). The highest level of increased in bulk density was found in the trail with 10% slope gradient between control and the treatments.

Discussion

Result shows that average bulk density significantly increased after rubber-tired skidder operations. However, in different slope gradient percentage of increased bulk densities were statistically different. Results of majority of studies were consistent with our result (Gayoso and Iroume, 1991; Rab, 1996; Kolkaa and Smidt, 2004; Horn *et al.*, 2004). Also, Horn *et al.* (2004) showed that each stress applied at the soil surface is always transmitted three dimensionally and causes not only soil compaction but also shear effects. Result shows that bulk density significantly increased as machine pass increased. In general, trails with four slopes show a similar trend of increasing soil bulk density with increasing amounts of machine passes. For most treatments, the highest rates of increase in bulk density were achieved in the first 5 to 15 machine passes. This agreed with Horn *et al.* (2004) who identified that subsequent machine passes increased the soil compaction at a lesser extent until there is little or no more compaction associated with a machine passes.

In this study, flat trails had the lowest bulk density; the trails with -10 and -20% slope gradient (downhill skidding) had intermediate bulk density and the trails with 10% slope gradient (uphill) have the highest compaction. This result can be explained based on the uneven load distribution between the tires of the skidder in the downhill and uphill skidding (Gayoso and Iroume, 1991; Ares *et al.*, 2005; Grace *et al.*, 2006; Ampoorter *et al.*, 2007; Jamshidi *et al.*, 2008). Ano-

Table 2. Analysis of variance (ANOVA) for the effect of sample position (compacted and control samples), slope gradient, and depth on bulk density in skid trails

Source	SS	df	MS	F	P
Slope	0.011	3	0.004	3.5	0.02
Position	1.403	1	1.403	1,347	0
Depth	0.816	2	0.408	391.5	0
Slope * Position	0.004	3	0.001	1.324	0.28
Slope * Depth	0.002	6	0	0.272	0.95
Position * Depth	0.101	2	0.05	48.43	0
Slope * Position * Depth	0.005	6	0.001	0.784	0.59

ther reason for lower bulk density at the downslope track might be the dragging of the logs on or close to this track. Dragged behind the skidder, the logs and especially the log heads might have ripped and loosened up the surface of the highly compacted the wheel track (Kozłowski, 1999; Rohand *et al.*, 2004; Eliasson and Wasterlund, 2007; Wang *et al.*, 2007). However, Gayoso and Iroume (1991) stated that this may be a consequence of the problems that the skidder might face when logging in steep terrains. In this study there was not only compaction at all three depths but with increasing soil depth the compaction level also increased, which is in agreement with the results of other researchers (Cullen, 1991; Horn *et al.*, 2004; Eliasson, 2005; Bolding *et al.*, 2009; Ampoorter *et al.*, 2010). This is related to the rather homogeneous weight distribution of the skidder on the flat skid trails.

Conclusions

According to our findings, we conclude that the skidding operations should be planned when soil conditions are dry so as to minimize rutting, but if skidding must be done under wet conditions, the operations should be stopped when machine traffic creates deep ruts. Hence, even one pass is already sufficient to induce a strong increase in bulk density. Also, slope gradients on trails should be as low as possible, particularly when vehicles are traveling loaded. Results of this research approved that preplanning of skid trails and directional felling will improve skidding efficiency, increase safety, and reduce ground disturbance. Designated skid trails should be used to reduce soil compaction, hence preserving the rest of the area.

Acknowledgements

The authors would like to acknowledge the financial support of the University of Tehran for this research under grant number 28514/1/4.

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